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A NEW PERSPECTIVE ON PARTON DISTRIBUTIONS IN NUCLEI

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Abstract

We present recent progress on the study of the deep inelastic structure of nuclei that improves our current understanding of the mechanisms of nuclear modifications of parton distribution functions.

1 Introduction

The determination of the quark and gluon structure of nuclei remains an important open, and currently unsolved question in Quantum Chromodynamics (QCD). Its detailed knowledge is, in fact, fundamental for understanding the occurrence of a deconfined quark-gluon phase both in the high baryon density regime present in neutron stars, and at high temperatures accessible both at the Relativistic Heavy Ion Collider (RHIC), and at the Large Hadron Collider (LHC). Moreover, the theoretical uncertainty related to nuclear effects hinders the extraction of possible contributions of new physics from a number of high precision experiments. This uncertaintly will be particularly felt in the forthcoming generation of experiments using neutrino beams [1].

Theoretical efforts have so far concentrated on two apparently distinct areas. Many studies were dedicated on one side to the interpretation of Deep Inelastic Scattering (DIS) experiments. In the past twenty years it has been established that sizable A-dependent effects affect nuclear DIS cross sections (for e recent review see [2]), thus suggesting that the nuclear parton distributions could not be described as a collection of "quasi-free" nucleons whose partonic structure would remain unaffected by the relatively weak nuclear forces. On the other side, a number of recent exclusive electron-nucleus scattering experiments allow for investigations of the nucleon form factors for bound nucleons. Their initial outcome is also suggestive of non trivial deformations of the charge and magnetic current distributions of bound nucleons [3].

Recently, a more comprehensive object, the Generalized Parton Distribution (GPD) was introduced that interpolates between the Parton Distribution Functions (PDFs) from DIS, and the form factors (for reviews see [4, 5]). GPDs are the soft components in the hadronic tensor for Deeply Virtual Compton Scattering (DVCS). A relation of GPDs to Wigner distributions was also recently uncovered in Ref. [6] after the initial observation that they carry information on the location of partons inside the hadron [7]. GPDs provide a unique tool to explore the spatial distributions of quarks and gluons in nuclei.

2 Nuclear Effects in Deep Inelastic Scattering: Status and Perspectives

The study of nuclear modifications of DIS type cross sections with respect to the free nucleon ones started in the mid 80's with the discovery by the EMC collaboration of up to 20% discrepancies in the iron structure function F_2, at values Bjorken $x \approx 0.5$. It is currently understood that there are four distinct regions characterized by nuclear effects of different nature: $x < 0.1$, the *shadowing* region, $0.1 < x < 0.2$, the *anti-shadowing* region, $0.2 < x < 0.6$ the

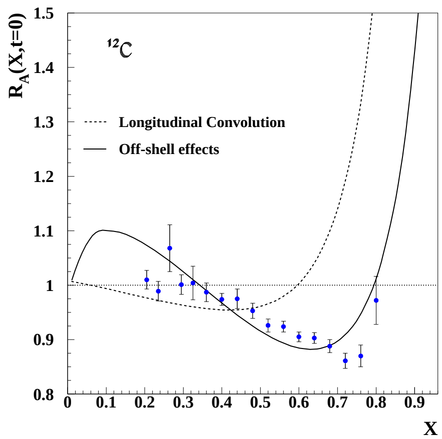

Figure 1: *Example of nuclear effects from a forward ($t = 0$) DIS experiment. Only data at large x are displayed Ref.* [9]*. The full curve is our current description of large x nuclear effects, including the effect of transverse degrees of freedom explained in the text. The dashed curve displayed for comparison, includes conventional nuclear degrees of freedom only.*

"EMC-effect" region, and $x > 0.6$, where nucleons' Fermi motion is assumed to dominate [2]. In Fig.1 we show the ratio, R_A, of the DIS nuclear structure function over the free nucleon one for ^{12}C. We focus on the region $x > 0.1$, *i.e.* we omit shadowing because the very different space-time characteristics of this phenomenon would deserve a separate and lengthier discussion. There is currently no definitive consensus on the physics underlying nuclear effects at $x > 0.1$. It is by now clear that the so-called Light Cone (LC) convolution approach (see [8] for a review) is inadequate to reproduce the effect. However, the picture is emerging that corrections to this approximation given in terms of the partons' transverse degrees of freedom, $k_\perp$, and off-shellness, which are related to parton interactions might play an important role. In Ref. [10], within Hard Scattering Factorization [11], it was shown that "active-$k_\perp$" effects on one side enhance the nuclear binding correction to the structure function, and on the other they are responsible for antishadowing. Inclusion of these effects produces the full curve in Fig.1.

We close this section by noting that while some of the puzzles concerning *e.g.* the role of particles off-shellness and/or re-interactions in nuclei will be addressed by dedicated inclusive scattering experiments *e.g.* in the Jefferson Lab program at 12 GeV [12], distinctively new type of information will also

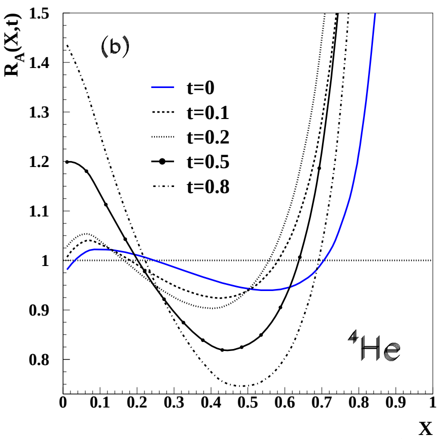

Figure 2: *Ratio of nuclear GPD in ^4He to the free nucleon one for different values of t.*

emerge from a class of exclusive type experiments measuring GPDs in nuclei, currently being considered.

3 Generalized Parton Distributions in Nuclei

In this Section we illustrate the new type of information on the DIS structure of nuclei that can be obtained from GPDs. The formalism for calculating GPDs in spin zero nuclei is described in [10]. The amplitude for DVCS is a generalization of the forward virtual Compton scattering one, whose imaginary part yields the DIS cross section, to the "off-forward" case namely when there is a momentum difference, Δ between the incoming and outgoing photon. In case of unpolarized scattering from a spin zero nucleus, it is parametrized in terms of a GPD, H_A which depends on two off-forward extra variables, denoted as $\zeta = \Delta^+/P^+$, P being the target's momemtum, and $t = -\Delta^2$.

In Fig.2 we show a ratio similar to the DIS ratio of Fig.1, of the nuclear GPD over the nucleon one, normalized by their respective form factors. All curves were obtained at $\zeta = 0$, namely the momentum difference is only transverse. The full curve in the figure corresponds to the forward case. One can notice an enhancement of both the antishadowing and EMC-effect regions with increasing t. In simple terms this is due to the fact that transverse d.o.f. and parton re-interactions are emphasized in a nucleus with respect to the free nucleon, and GPDs are a more sensitive probe of such components than in the forward, inclusive scattering case. Technically, the enhancement with respect to the forward case is obtained because nuclear GPDs are described in terms of t-dependent nuclear binding and average transverse momenta contributing to particles' off-shellness. One is therefore dealing withr a sort of binding and transverse momentum "form factors" rather than the given, fixed experimental values determining the forward DIS case (Fig.1).

In conclusion, the graphs in Fig2 illustrate a simple example of the many possibilities for a new insight into the deep inelastic structure of nuclei offered by considering a new class of exclusive experiments including DVCS. We have shown in particular that parton interactions/off-shellness that have been advocated as one of the possible explanations of the differences between the bound and free nucleons structure functions, are enhanced in the off-forward case. Many other aspects including the transverse spatial structure of nuclei and the connection with in medium properties of the nucleon [10], are currently also being studied.

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